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DIFFUSION IN THE VICINITY OF STANDARD-DESIGN NUCLEAR POWER PLANTS—II

WIND-TUNNEL EVALUATION OF BUILDING-WAKE CHARACTERISTICS

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Abstract—Laboratory experiments were conducted to simulate radiopollutant effluents released to the atmosphere from two standard-design nuclear power plants. The main objective of the study was to compare the dispersion in the wakes of the plants with that in a simulated atmospheric boundary layer. Dispersion functions are determined that describe the spread of the effluent plume in the wake of each plant. These dispersion functions are described by power laws. They are determined for three incident wind angles and the number of stacks associated with each plant. Lateral plume spread was directly related to the silhouette area of the plants. A graphical technique is presented relating the lateral dispersion to the associated silhouette area of the building or building complex.

INTRODUCTION

An important energy source for electrical power generation is the light-water-cooled reactor (LWR) nuclear power facility. The two most common types of LWR facilities are the boiling water reactor (BWR) and the pressurized water reactor (PWR). Relative to health, safety, environmental impact, and building design, an important consideration of an LWR facility is the assessment of any nuclear, as well as conventional, pollutants that might be released. Environmental impact calculations of the atmospheric transport of radiopollutants are usually based on the Gaussian equation for turbulent diffusion of passive contaminants in the atmosphere. Consequently, diffusion experiments deal with the determination of diffusion parameters (Gaussian standard deviations), as well as other relevant parameters, for different structural, meteorological, topographical, and release conditions. A

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variety of diffusion parameter data sets, derived by various methods and applicable to various situations, are used.

The effect of the wake downwind of a power plant on the diffusion parameters (σ_y and σ_z) and the validation of the variation of diffusion parameters are among the areas identified as needing further research (Ho78). There are numerous mathematical models available that can be used to assess the radiological consequences of routine and accidental releases of radionuclides from nuclear power facilities. Information extracted from such models can be inherently uncertain, since the transport and dose can only be approximated. To examine the usefulness of a model as an assessment tool, a determination of the extent of this uncertainty is required.

Until recently, these uncertainties had not aroused much interest in the scientific community because of the conservative nature of the model predictions. This conservative nature was due to the adoption of conservative assumptions about exposure pathways, parameter values, and receptor characteristics. In the past, this approach was acceptable because model predictions were only a small fraction of the applicable standards, and the probability of individuals receiving doses in excess of the model predictions was remote. Increasingly restrictive radiological protection standards have revived interest in developing more accurate models. To bring model predictions into a more realistic realm, model parameters and basic assumptions must be reevaluated to determine the predictive capabilities of the various models used in radiological assessments.

Government, as well as industry, strongly desires to establish "standard nuclear power plant designs", especially for BWR and PWR facilities. At present, there are approximately four architect-engineering (A/E) companies in the United States involved in the standardization of LWR nuclear power facilities. Three A/E companies are working with the standard design of PWR systems and one is involved with the standard design of the BWR system. The goal is to reduce licensing time, engineering effort, construction schedules, and cost as well as better availability of money. Standardization would help to reduce the chances of design errors, since construction changes would vary little from one plant to the next. Also, fewer site-specific variables would considerably reduce A/E work loads. The reduction in site-specific variables also has definite advantages when estimating atmospheric transport and dispersion of gaseous effluent releases from LWR nuclear power facilities.

The purpose of this study was to determine, through wind tunnel experiments, the diffusion parameters needed to update dose calculations relative to the dispersion of radiopollutants near standardized plants. In the wind tunnel, effluent concentrations were measured in the vicinity of the model facilities. Dispersion parameters were measured for three incident wind angles with two and four release points for the PWR and BWR, respectively. Ethylene was released from the model plants as a tracer, and a flame ionization detector (FID) was used to obtain quantitative measurements of dispersion patterns.

The investigation of building-wake effects associated with standard-design nuclear power plants will aid in assessing the near-building and downwind hazard associated with releases of radioactive effluents. The overall study provided a much needed interface between the point of effluent release and the usually assumed Gaussian plume. The simulated neutral suburban atmospheric boundary layer in which the model plants were immersed is described in Part I.

This wind tunnel study was limited to the simulation of neutral flow conditions and does not address the current problem of low wind speed, inversion conditions where wind meander may become a significant dispersion mechanism. In principle, concentration patterns observed under different wind directions cound be superposed to obtain longer term average concentrations, thus accounting for wind meander effects, but additional study is required to determine the feasibility of such.

EXPERIMENTAL EQUIPMENT AND PROCEDURES

Design of the experiment

The study consisted of qualitative and quantitative experimentation. The primary objective was to determine building-wake effects by measuring effluent concentration fields associated with two standard-design nuclear power plants for three incident wind angles. The examination of building wakes and the parameter comparisons were quantitative. Flow visualization by photographing an oil fog effluent comprised the qualitative part of the study, which corroborated the quantitative concentration data.

Three models were used: an isolated stack (described in Part I), a standard-design PWR plant and a standard-design BWR plant. The isolated stack model (Stack) was used to determine the dispersion characteristics of the simulated atmospheric boundary layer. The two standard-design plants were examined to determine the building-wake effects associated with the dispersion of effluent releases. The standardized plants used were the Standard Nuclear Power Plant System (SNUPPS), a PWR plant vended by the Bechtel Corporation, Gaithersburg, Maryland, and the Standard Reactor Island Design (STRIDE), a BWR plant vended by C. F. Braun and Company, San Jose, California. These two plants were selected because STRIDE is the only standardized BWR power plant and SNUPPS is quite similar in shape to the other PWR standard designs.

The study focused on near-field effluent concentrations in the range from the immediate vicinity to approx. 20 building heights downwind. The models were constructed of acrylic plastic, except for the domes which were made of wood and the stacks which were brass tubes. A model-to-prototype scale ratio of 1:300 was followed.

The wind tunnel arrangement was identical to that previously discussed in Part I (see Fig. 1, Part I), except, of course, that the models were placed in the tunnel at the position of the isolated stack. Instrumentation and procedures are also discussed in Part I.

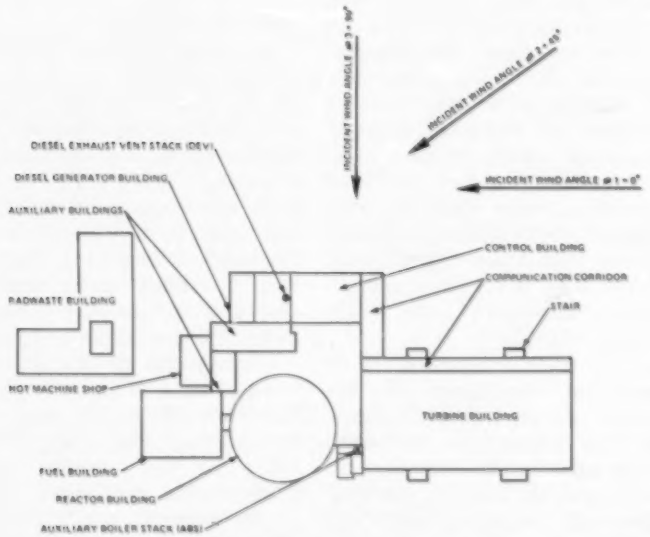

FIG. 1. Plan view of SNUPPS model.

Similarity criteria

For the behavior of the flow in the wind tunnel to simulate that in the atmosphere, it was necessary to match certain nondimensional parameters (Sn72, 81). For the present study, the parameters of significance were:

$$\frac{L}{h}, \frac{D}{h}, \frac{h_s}{h}, \frac{\delta}{h}, \frac{W}{U}, \frac{Uh}{\nu}, \frac{WD}{\nu}.$$

The building-complex width-to-height ratio is L/h; the stack diameter to building height ratio is D/h; the stack height to building height ratio is h_s/h; and the boundary layer thickness to building height ratio is δ/h. All satisfied the similarity criteria because the models were scaled versions of the full-scale plants. The effluent exit speed to wind speed ratio, W/U, determines the plume rise for a nonbuoyant plume. This ratio was strictly modeled on information provided by utilities and architect-engineers.

The final two similarity criteria considered were the building-complex Reynolds number, $Re_b = Uh/\nu$, and the effluent Reynolds number, $Re_e = WD/\nu$. For exact similarity, both Reynolds numbers of the model must match those of the prototype. Such matching was not possible, however, because of the scale of the models that was used. Fortunately, these criteria can be relaxed. At sufficiently large Reynolds numbers, the flow patterns become independent of Reynolds number (Sn72). In the present study, building Reynolds numbers ranged from approx. 60,000 to 80,000 with a freestream wind speed of 6 m/s. These values are well above critical Reynolds numbers associated with sharp-edged buildings and are of the same order-of-magnitude as critical values associated with more streamlined buildings (Ha77).

It was imperative that the approach flow simulate atmospheric conditions as accurately as possible. In neutral atmospheric flows, all major flow systems are turbulent, and viscous forces are relatively unimportant. Thus, except very near the surface, the flow is considered Reynolds-number independent. If the surface is roughened such that the irregularities are larger than the thickness of the viscous sublayer, then an aerodynamically rough surface is created (Su49). The domes and cylinders associated with the two models were covered with sand, attached by epoxy cement. The sand caused protrusions upon the surface approx. 1 mm high. Snupps, the power plant with a hemispherical dome, was designed with structural supports that acted as trips to aid in the transition to turbulent flow. STRIDE had a dome of large curvature and a sharp edge at the top of the cylindrical reactor building. The design features and the roughened surfaces helped insure an aerodynamically rough surface so that the flow was Reynolds-number independent (Sl68).

The criterion of turbulent flow associated with the effluent Reynolds number WD/ν was also satisfied. A trip consisting of an internally serrated washer was placed inside the stack, 10 diameters upstream from the exit, to insure a fully turbulent flow upon release (Li76). This technique enabled the plume behavior to be independent of effluent Reynolds numbers (Sn76). Effluent Reynolds numbers ranged from 1250 to 2050 without the trips.

Flow visualization

An extensive flow visualization study was conducted prior to concentration measurements. Smoke for the qualitative flow study was produced by a paraffin oil fog generator, which operates by aspirating paraffin oil onto a heating element which creates a fine oil fog. Flow rates associated with the various stacks were monitored with Meriam Laminar Flow Elements, which were checked for accuracy with a bubble meter and stopwatch. The smoke generator was connected in-line between the laminar flow element and the stack.

Photographs of the smoke patterns were taken with a 35 mm camera using ASA 400 black-and-white film and ASA 160 color transparency film. Side views and overhead views of each model, angle, and stack configuration were taken. Photographs taken at an ambient wind speed of 6 m/s and effluent emission rates prescribed by the scaling proved to be of little value because

the smoke plumes were not dense enough to produce adequate photographs. Each plume was visually evaluated under the above release conditions, the wind speed and emission rate were reduced by a factor of 3, and the plumes were reevaluated visually. No noticeable changes were observed in the plume characteristics. All photographs were subsequently taken under the reduced flow speeds.

Standard Nuclear Unit Power Plant System (SNUPPS)

The SNUPPS model was utilized to determine the building-wake effects associated with effluents released from a standard design PWR nuclear power plant. The model had maximum overall dimensions of 86.2 × 35.4 × 21.3 cm. Figures 1 and 2 show plan and elevation views of the SNUPPS model. The stack diameters and exit velocities of the effluent were modeled to stimulate those of an operating, full-scale plant. Releases were neutrally buoyant. Table 1 provides a summary of the SNUPPS release data.

The dispersion was examined for effluent releases at three different incident wind directions. Since most dispersion corrections for wake effects are associated with building dimensions (height, width, or cross-sectional area), the incident wind directions were selected to maximize and minimize the dimensions associated with the building-complex. Figure 1 depicts incident wind angles 1(0°), 2(45°) and 3(90°), which correspond to the minimum, the maximum, and an intermediate cross sectional area, respectively. Measurements were taken for effluent releases from each stack and for each wind direction.

Standard Reactor Island Design Model (STRIDE)

The STRIDE model was used to determine the building-wake effects associated with effluents released from a standard design BWR nuclear power plant. The model has maximum overall dimensions of 61.0 × 70.5 × 17.4 cm. Figures 3 and 4 provide plan and elevation views of the STRIDE model. The stack diameters and exit velocities of the effluent were modeled to simulate those of an operating full-scale plant. Releases were neutrally buoyant. Table 2 provides a summary of the STRIDE release data.

Dispersion from the STRIDE model was also examined for effluent releases at three different incident wind angles. Figure 3 illus-

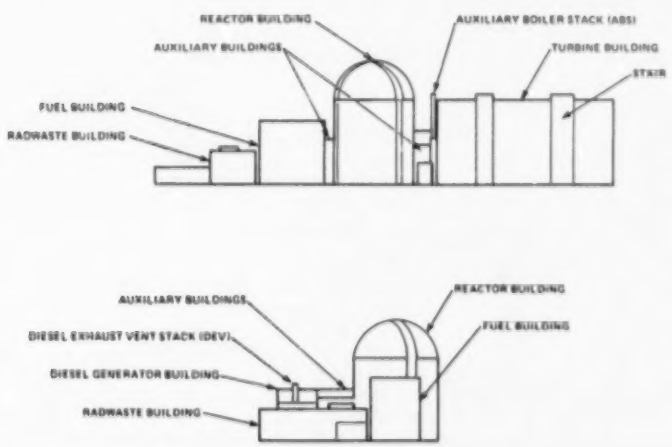

FIG. 2. Elevation view of SNUPPS model.

Table 1. SNUPPS release data

Parameter	Full Scale	Model Scale
ABS[a] inside diameter	2.1 m (7 ft)	0.71 cm (9/32 in)
ABS stack height	47.7 m	15.9 cm
ABS release rate	10.8 m^3/s (23,000 CFM)	6300 cc/min
DEV[b] inside diameter	0.6 m (2 ft) (2 stacks)	0.39 cm (5/32 in) (1 stack)
DEV stack height	29.7 m	9.9 cm
DEV release rate	2.36 m^3/s (5,000 CFM)	2900 cc/min

(a) ABS = auxiliary boiler stack; (b) DEV = diesel exhaust vent

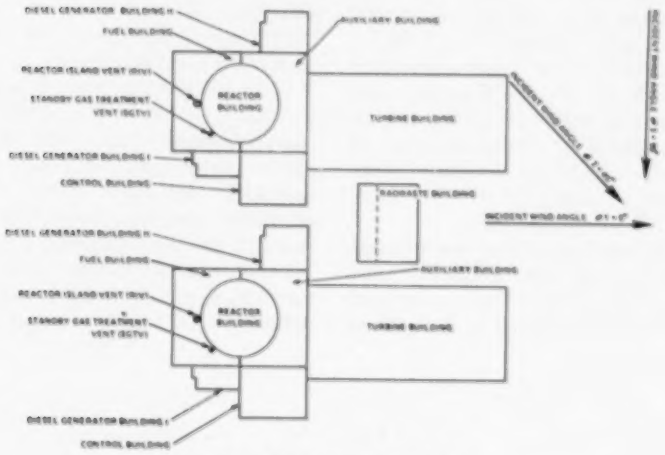

FIG. 3. Plan view of STRIDE model.

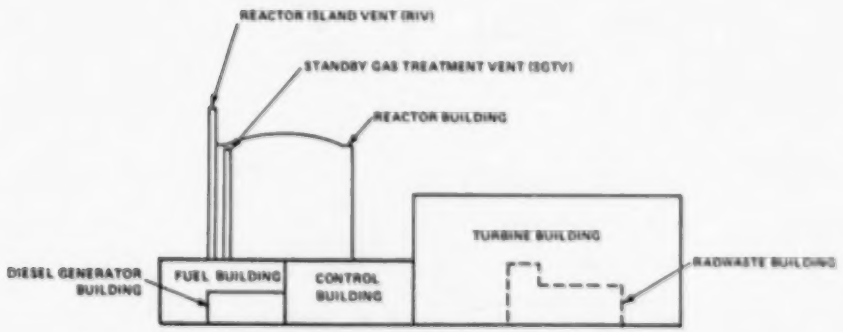

FIG. 4. Elevation view of STRIDE model.

Table 2. STRIDE release data

Parameter	Full scale	Model scale
RIV[a] inside diameter	1.5 m (5 ft)	0.51 cm (7/32 in)
RIV stack height	58.2 m	19.4 cm
RIV release rate	10.8 m^3/s (23,000 CFM)	7.300 cc/min
SGTV[b] inside diameter	0.5 m (18 in)	0.16 cm (1/16 in)
SGTV stack height	46.8 m	15.6 cm
SGTV release rate	2.36 m^3/s (5,000 CFM)	1,700 cc/min
(a) RIV = reactor island vent; (b) SGTV = standby gas treatment vent		

trates incident wind angles 1(0°), 2(45°) and 3(90°), which correspond to intermediate, maximum, and minimum cross sectional areas, respectively. Measurements were taken for effluent releases from each stack and for each wind direction.

RESULTS AND DISCUSSION

Flow visualization

Flow visualization was used to evaluate the qualitative features of the dispersion and to determine sampling positions for the concentration measurements. Plume trajectories were examined for both models, SNUPPS and STRIDE.

Figure 5(a) shows smoke being released from the auxilliary boiler stack of the SNUPPS model at a 0° incident wind angle. The effluent rapidly fills the wake and is swept downwind. A view with a wind angle of 90° and a release from the diesel exhaust vent is shown in Fig. 5(b). The plume does not disperse rapidly until contact is made with the reactor building, but its path is highly disturbed; the plume follows the streamlines over the dome, then quickly disperses in the cavity and wake regions.

Figures 6 shows instantaneous and time-lapse photographs of smoke being released from the STRIDE model. The plant is oriented at 0° and the effluent is being released from both reactor island vents. Figure 6(b) provides a good representation of the entire wake envelope associated with this plant orientation.

Building wake effects

Lateral and vertical concentration profiles were measured in order to determine the plume standard deviations. These profiles were measured at four locations downwind of the plants. The vertical profiles were obtained at locations directly downwind of the stack releasing the effluent, and the lateral profiles were taken at the heights of the maxima in the vertical profiles. When the stack was located at the downwind edge of the building complex, the lack of a sufficient distance for turbulent mixing to occur resulted in extremely strong and narrow plumes. Plumes from stacks located at the upwind edge of the building complex were mixed throughout the cavity region. These effects resulted in extremely large variations in the calculated standard deviations for the measurements very close to the plants. They were not prevalent in the three measurements farther downwind. Thus, only the data taken at the three most-downwind locations were used in the analysis. Inferences concerning plume characteristics within the cavity of the building complexes are not attempted.

The analysis consisted of applying a linear, least-squares fit to the plume standard deviations for each release or group of releases. A slope and intercept were determined for each release case. Each calculated slope and intercept described a function that represented the plume spread associated with the specific release situation. These functions were compared with the techniques set forth in Regulatory Guide 1.111 (Nu77) of the U.S. Nuclear Regulatory Commission (NRC).

Wake functions were examined for effects associated with different incident wind angles and different stack releases for each power

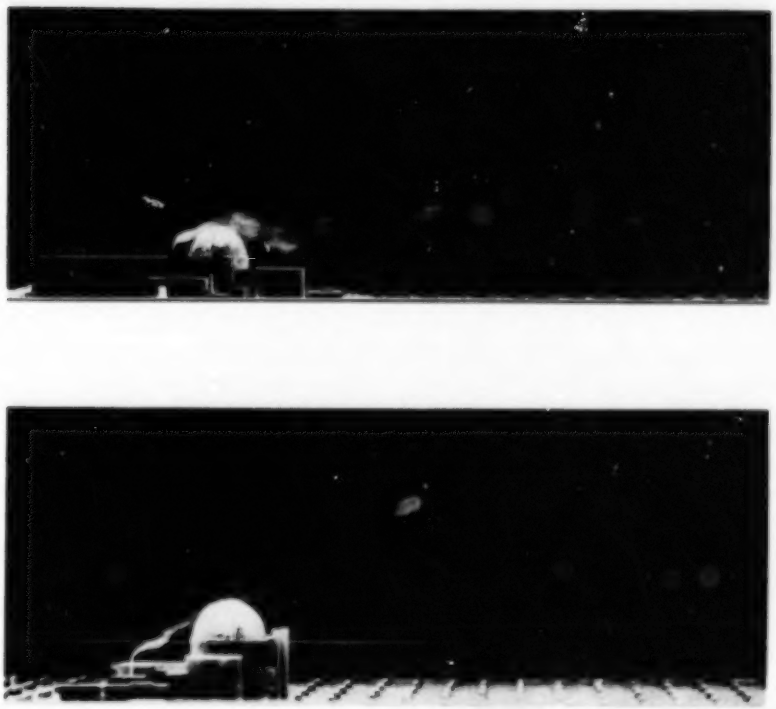

FIG. 5. Releases from the SNUPPS model: (a) ABS for 0° wind angle and (b) DEV for 90° wind angle.

plant. The major effects on the wake functions were associated with different wind angles and not with different release positions. Stack position within the plant complex undoubtedly has an effect upon the wake functions (Th77); however, because of the complex structure of the plants in the present study, these effects were minimal.

Building wake corrections

The NRC allows an adjustment for the vertical standard deviation for ground-level releases of an effluent plume released within the building wake. This adjustment is an adaptation of work done by Yanskey *et al.* (Ya66), who applied a corrected standard deviation Σ of the form

$$\Sigma = (\sigma^2 + A/2\pi)^{1/2}$$

for measurements beyond 100 m, where A is the projected area of the plant normal to the wind direction and σ is the standard deviation of the plume spread. The NRC has modified this method in Regulatory Guide 1.111 (Nu77). For ground-level releases of the effluent plume within the building wake, the Guide recommends the use of

$$\Sigma = (\sigma_z^2 + h/2\pi)^{1/2}$$

if $\Sigma \leq \sqrt{3}\sigma_z$, otherwise $\Sigma = \sqrt{3}\sigma_z$, where h is the maximum height of the power plant and σ_z is the standard deviation of the vertical plume spread.

Figures 7 and 8 are plots of Pasquill-Gifford (PG) dispersion curves corrected using the NRC method as applied to the SNUPPS power plant. The PG functions are

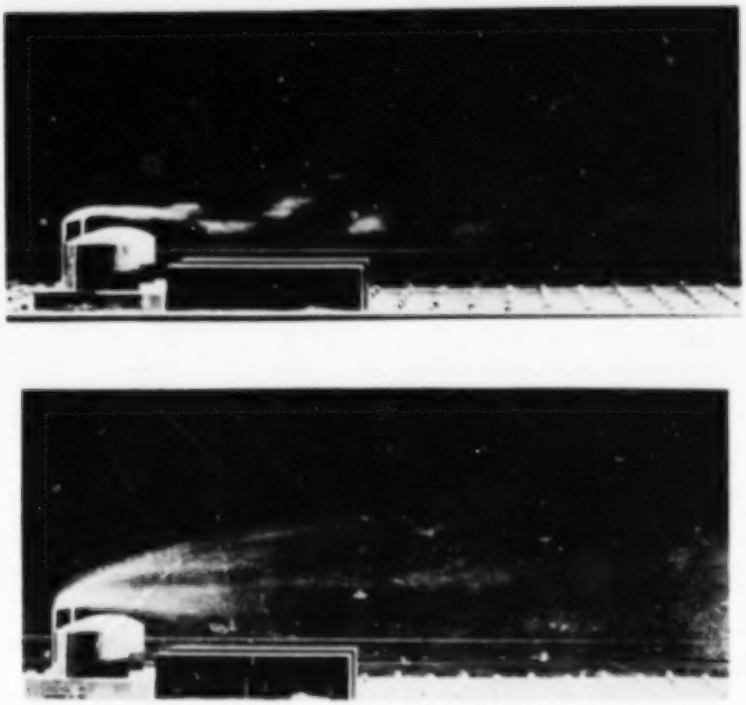

FIG. 6. Releases from the STRIDE model RIV for 0° incident wind angle: (a) instantaneous and (b) 10-sec continuous exposure.

those most commonly used in dispersion calculations. The NRC wake correction without the restriction that $\Sigma = \sqrt{3\sigma}$ for values of $\Sigma > \sqrt{3\sigma}$ is also shown and is labeled "unrestricted wake correction". The NRC wake correction causes a maximum increase in dispersion of approximately one stability class and is asymptotic to the PG curves at large distances. For the unrestricted wake correction, very large increases are obtained close to the power plants. The restriction is based on limited tracer studies by Dickson *et al.* (Di69), which showed an average dilution ratio of 3 for undisturbed flow versus disturbed flow.

Building wake functions for the SNUPPS and STRIDE power plants

For the SNUPPS model, the lateral and vertical building wake functions associated with the three incident wind angles are displayed in Fig. 9. Lateral dispersion indicated a direct relationship with the silhouette or projected area of the power plant; the building orientation with the largest projected area created the largest wake and that with the smallest created the smallest wake. Vertical dispersion was, at best, weakly related to silhouette area. For wind angles perpendicular to the major axes of the SNUPPS model, 0° and 90°, plume spread was proportional to projected area. For a wind angle of 45°, the effects were quite different. The wake exhibited less spreading initially but grew much quicker. A similar finding was reported by Thompson and Lombardi (Th77) for a cube-shaped structure, where a wind direction of 45° caused an increase in the maxi-

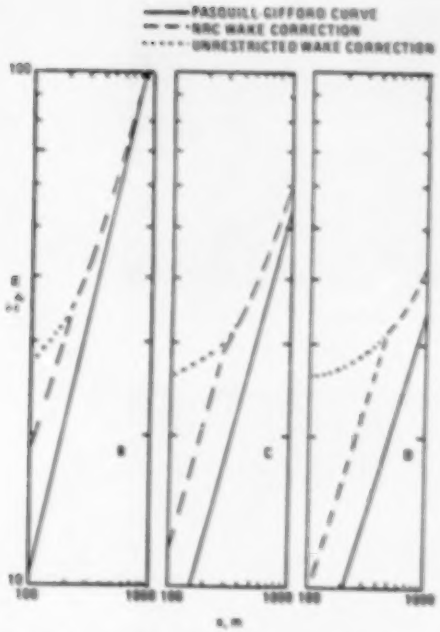

FIG. 7. Pasquill–Gifford vertical dispersion curves plotted with the NRC building-wake correction and the "unrestricted" wake correction for the SNUPPS plant.

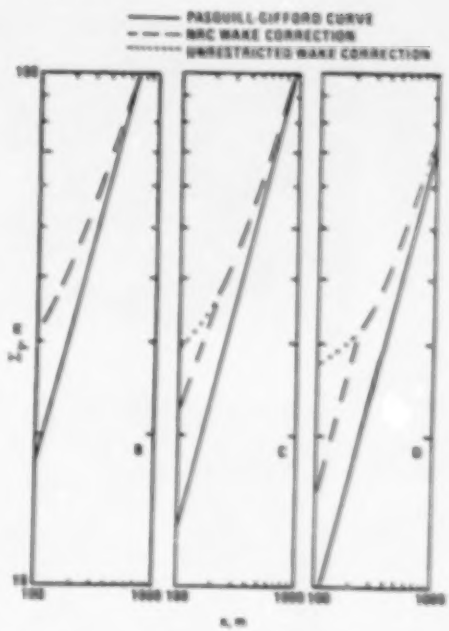

FIG. 8. Pasquill–Gifford lateral dispersion curves plotted with the NRC building-wake correction and "unrestricted" wake correction for the SNUPPS plant.

mum ground-level concentration of a factor of six. This increase as well as an increase in the width of the dispersion envelope were thought to be due to the flow separating at the corners of the building to produce standing vortices.

For the STRIDE model, the wind angle had less influence, as shown in Fig. 10. Lateral dispersion was essentially independent of wind angle. This may be attributed to the very similar values of projected building area for all three wind angles. The vertical wake functions were not related significantly to the dimensions of the plant.

Comparisons of the derived building wake functions with the NRC wake corrections are also presented in Fig. 9 and 10. In all cases, the dispersion was greater for the derived wake functions than for the NRC functions. This indicates the conservative nature of the NRC method for calculating concentrations and doses.

Tables 3 and 4 list the linear regression parameters for each set of concentration profiles associated with the different release situations. Also listed are regression parameters for groups of all vertical and lateral data, and data associated with each wind angle. With these data and the associated error sum-of-squares, a general linear test approach (Ne74) was used to determine if groups of regression lines were identical. The test statistics used follows the F-distribution and has the form

$$F = \frac{SSE(R) - SSE(F)}{\mathrm{d}\,f(R) - \mathrm{d}\,f(F)} \div \frac{SSE(F)}{\mathrm{d}\,f(F)},$$

where SSE is the error sum-of-squares, $\mathrm{d}f$ is the number of degrees of freedom, and R and F indicate the reduced and full models, respectively. The risk of making a Type I error was controlled at 5%.

For the SNUPPS plant, there was a

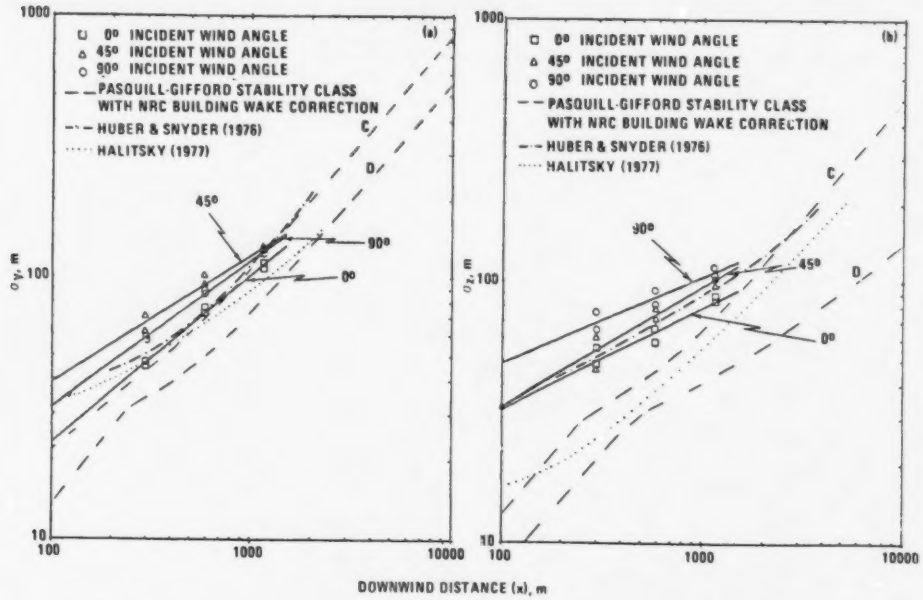

FIG. 9. Building-wake functions for the SNUPPS model: (a) lateral and (b) vertical.

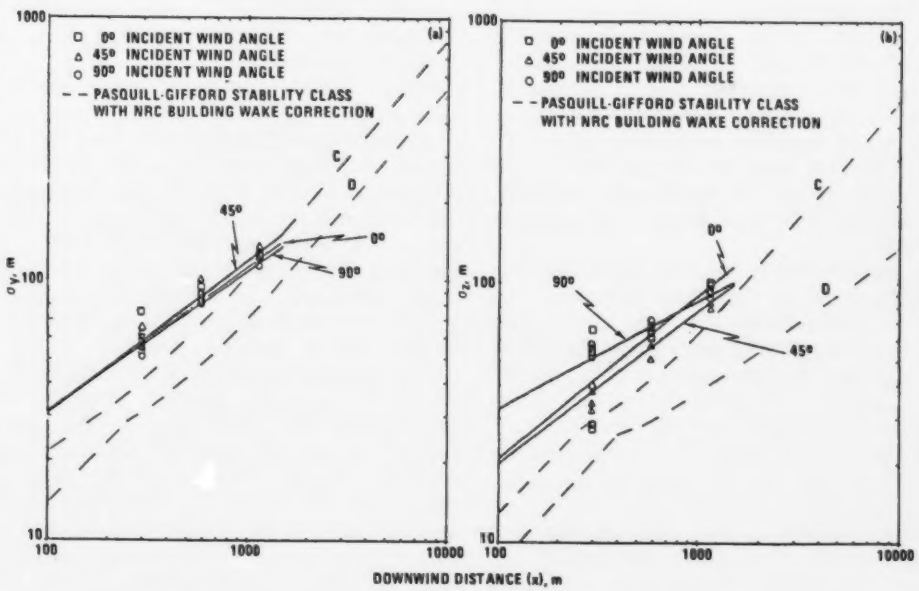

FIG. 10. Building-wake functions for the STRIDE model: (a) lateral and (b) vertical.

Table 3. Regression parameters for a plot of $\log_{10}(\sigma)$ (distance downwind) for the SNUPPS model

Direction of Dispersion	Incident Wind Angle	Release Point(s)	Correlation Coefficient (R^2)	Slope (B_1)	Intercept (B_o)
Lateral	All angles	All points	0.87	0.56	0.36
	0°	ABS[a]	0.99	0.67	0.00
		DEV[b]	0.99	0.61	0.18
		All 0° releases	0.99	0.64	0.09
	45°	ABS	0.98	0.43	0.79
		DEV	0.98	0.54	0.44
		All 45° releases	0.94	0.49	0.61
	90°	ABS	0.98	0.55	0.41
		DEV	0.99	0.57	0.35
		All 90° releases	0.98	0.56	0.38
Vertical	All angles	All points	0.65	0.40	0.77
	0°	ABS	0.87	0.30	1.02
		DEV	0.98	0.49	0.42
		All 0° releases	0.82	0.39	0.72
	45°	ABS	0.99	0.53	0.35
		DEV	0.98	0.40	0.82
		All 45° releases	0.82	0.47	0.58
	90°	ABS	0.99	0.29	1.16
		DEV	0.98	0.38	0.87
		All 90° releases	0.85	0.34	1.01

(a) ABS = auxiliary boiler stack
(b) DEV = diesel exhaust vent

significant difference between the wake functions for lateral dispersion associated with the 0°, 45 and 90° wind angles. Scrutinizing the situation more thoroughly revealed a significant defference between the lateral wake function associated with a 0° wind angle and those for 45 and 90°. A test between the 45 and 90° wind angles indicated no significant difference. Figure 9(a) supports the above results.

For vertical dispersion associated with the SNUPPS plant, no significant difference was found to exist between the three wind angles or between any pair of wind angles. It should be noted that the comparison of 0 and 90° wind angles was quite close to being significant, as indicated by Fig. 9(b).

For the STRIDE model, no wake function was determined to be different from its cohorts for lateral or vertical dispersion.

Figures 11 and 12 are plots of intercept versus slope for the lateral and vertical dispersion associated with each individual release case for the SNUPPS and STRIDE models, respectively. A characteristic of all the plots of regression parameters is the linear relationship.

Figure 11(a) for the SNUPPS model is quite interesting. For lateral dispersion, there is a distinct relationship between the projected building area and the regression parameters. Building areas were assigned to the least-squares fit to conform to values associated with the SNUPPS plant. By selecting a projected building area within the range indicated on the figure, regression parameters that describe the wake region can be read directly from the figure.

The general linear tests to determine if groups of regression lines are identical are in direct agreement with Figs. 11 and 12. In Fig. 11(a), the 45° and 90° data are very closely related, whereas the 0° data are somewhat segregated. In Figs. 11(b), 12(a) and (b), there is no definite relationship between the regression parameters associated with the incident wind angles, as was also indicated in the statistical tests. These data

Table 4. Regression parameters for a plot of $\log_{10}(\sigma)$ vs $\log_{10}$ (distance downwind) for the STRIDE model

Direction of Dispersion	Incident Wind Angle	Release Point(s)	Correlation Coefficient (R^2)	Slope (B_1)	Intercept (B_0)
Lateral	All angles	All points	0.91	0.56	0.36
	0°	SGTV(1)[a]	0.99	0.71	-0.07
		SGTV(2)	0.90	0.29	1.16
		RIV(1)[b]	0.99	0.60	0.23
		RIV(2)	0.91	0.62	0.19
		All 0° releases	0.86	0.56	0.38
	45°	SGTV(1)	0.99	0.47	0.66
		SGTV(2)	0.97	0.55	0.45
		RIV(1)	0.99	0.62	0.18
		RIV(2)	0.99	0.68	0.02
		All 45° releases	0.92	0.59	0.30
	90°	SGTV(1)	0.99	0.52	0.50
		SGTV(2)	0.99	0.50	0.54
		RIV(1)	0.99	0.57	0.33
		RIV(2)	0.99	0.58	0.29
		All 90° releases	0.97	0.54	0.41
Vertical	All angles	All points	0.69	0.55	0.29
	0°	SGTV(1)	0.91	0.40	0.77
		SGTV(2)	0.91	0.94	-0.88
		RIV(1)	0.83	0.22	1.28
		RIV(2)	0.93	0.98	-0.94
		All 0° releases	0.96	0.54	0.21
	45°	SGTV(1)	0.96	0.54	0.21
		SGTV(2)	0.92	0.76	-0.34
		RIV(1)	0.75	0.28	1.04
		RIV(2)	0.96	0.79	-0.41
		All 45° releases	0.80	0.59	0.12
	90°	SGTV(1)	0.99	0.41	0.70
		SGTV(2)	0.90	0.32	0.95
		RIV(1)	0.81	0.32	0.96
		RIV(2)	0.95	0.63	0.08
		All 90° releases	0.85	0.42	0.67

(a) SGTV = standby gas treatment vent
(b) RIV = reactor island vent

imply a relationship between lateral wake characteristics and significant differences in projected building area.

Normalization of derived wake junctions

If the derived building-wake functions could be adequately related to a physical aspect of their respective power plants, it might be possible to correlate standard deviations for any wind angle when specific wind direction data are known. This might be accomplished by normalizing just the standard deviation σ or both the standard deviation and the downwind distance, σ and x, respectively. Most normalizations were performed on the SNUPPS data due to the greater difference in wake-function values.

In Fig. 13, the wake functions are normalized relative to the maximum building dimension in the direction of the dispersion. This technique met with little success. In Figs. 14(c) and (d), the square root of the projected building area was applied as the normalizing parameter with considerably more sucess. The data for lateral dispersion are seen to be reasonably collapsed in Fig. 14(c). A normalizing parameter of projected area is shown in Fig. 14(a) and (b). These figures support the previous discussion relating plume spread to building dimensions.

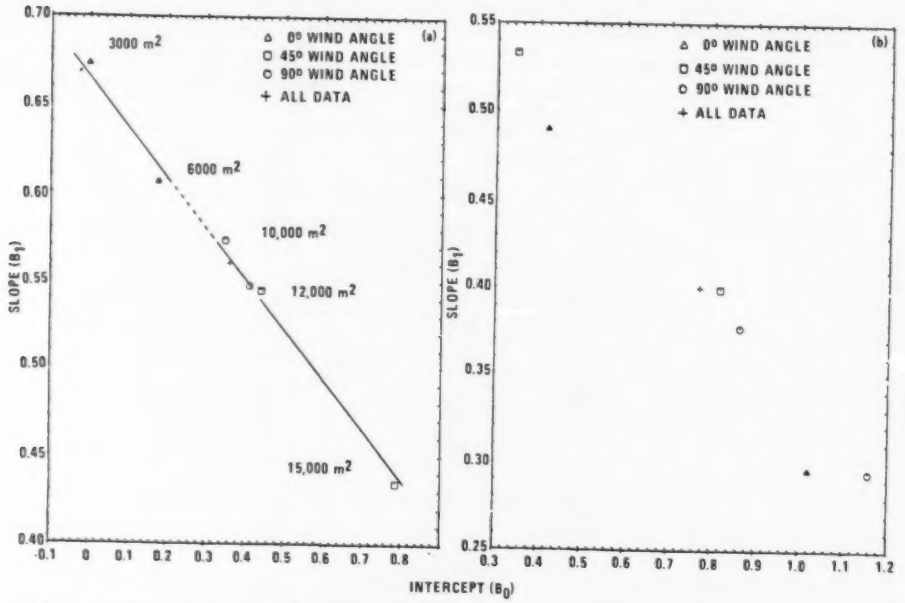

FIG. 11. Wake functions for all SNUPPS release cases plotted by regression parameter: (a) lateral with estimated projected building areas and (b) vertical.

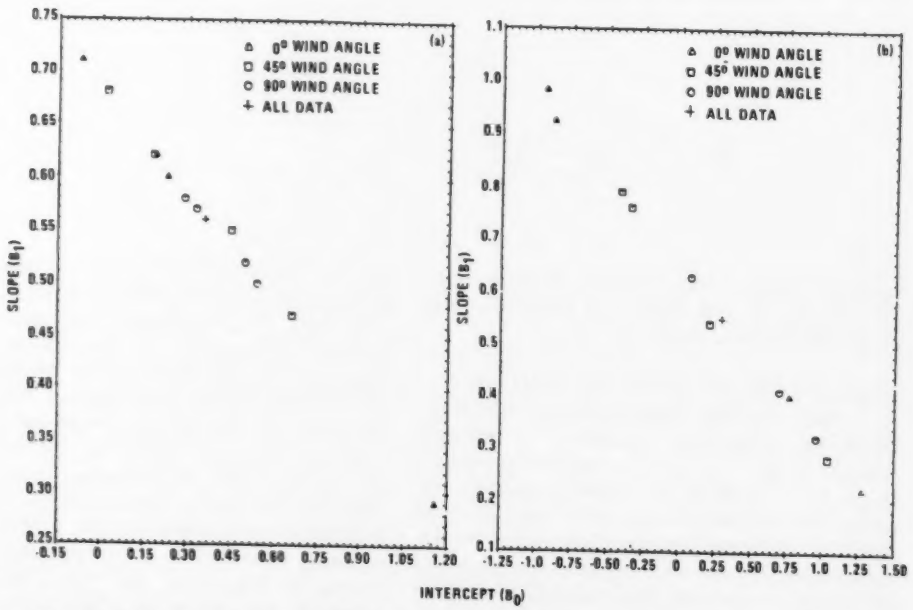

FIG. 12. Wake functions for all STRIDE release cases plotted by regression parameter: (a) lateral and (b) vertical.

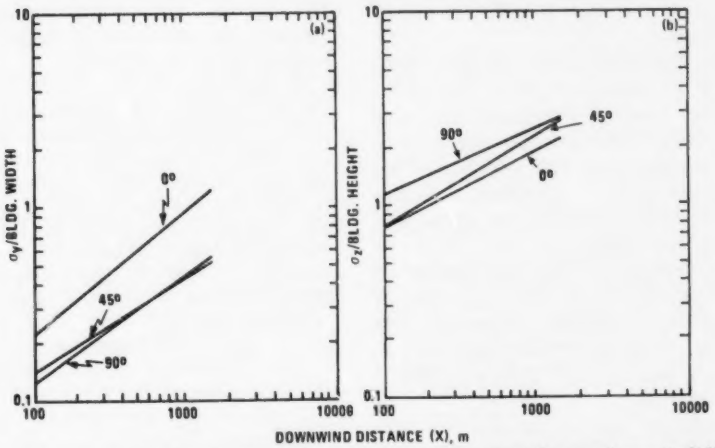

FIG. 13. Wake functions for the SNUPPS model normalized by the maximum building width or height: (a) lateral and (b) vertical.

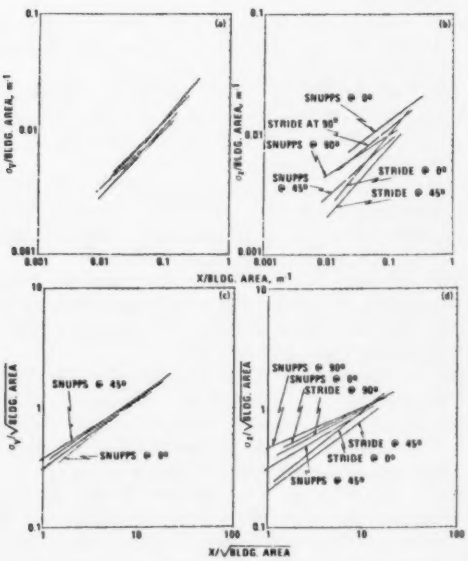

FIG. 14. Comparison of SNUPPS and STRIDE wake functions.

Combining the SNUPPS and STRIDE wake functions helps to illustrate the overall sucess in normalizing laterally and the inadequacy of normalizing vertically. Figure 14 shows the success accomplished for lateral normalization. For all projected areas associated with both models, the SNUPPS model at 45 and 0° represents the maximum and minimum, respectively. As might be expected, Fig. 14(c) indicates the largest and smallest functional values to be those associated with the SNUPPS model at 45 and 0°, respectively. This corroborates the direct relationship between wake characteristics and projected building area for lateral dispersion. Vertical dispersion does not exhibit such characteristics.

CONCLUSIONS

Wake effects for the two standardized nuclear power plants were described by plume standard deviations. For the power plant with the greater ratio of length to width, a change in incident wind angle altered the plume spread by as much as a factor of two, and in one case, altered the rate of growth of the plume. In all cases, lateral plume spread was directly related to the silhouette area of the buildings. For both power plants, the measured plume spread was not noticeably different for different stacks. The indistinguishability between different stack releases was ascribed to the high turbulence

and rapid mixing associated with structures of complex shape.

In all cases, the lateral and vertical standard deviations calculated with the NRC building wake correction formula were smaller than those measured in the laboratory. This is a trend that indicates the NRC building-wake-correction calculations consistently yield over-estimates of maximum concentrations and doses.

A graphical method to determine the lateral plume spread in the wake of a building or building complex of known projected area was developed. This technique promises to be of practical use in calculating building-wake characteristics.

Attempts were made to relate the calculated building-wake functions to physical aspects of the individual power plants. The silhouette or projected area and, to a lesser degree, the square root of the silhouette or projected area proved to be normalizing factors for lateral plume spread. No such simplification was found for vertical plume spread.

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REFERENCES

Di69 Dickson C. R., Start G. E. and Markee E. H., Jr., 1969, "Aerodynamic Effects of the EBR-II Reactor Complex on Effluent Concentration", *Nucl. Safety* **10**, 228–252.

Ha77 Halitsky J., 1977, "Wake Dispersion Models for the EBR-II Building Complex", *Atmos. Envir.* **11**, 577–596.

Ho78 Hoffmann F. O., Shaeffer D. L., Miller C. W. and Garten C. T. (Editors), 1978, *Proc. of a Workshop on the Evaluation of Models Used for the Environmental Assessment of Radionuclide Releases.* CONF-770901. Oak Ridge National Laboratory, Oak Ridge, TN.

Li76 Liu H. T. and Lin J. T., 1976, Plume Dispersion in Stably Stratified Flows over Complex Terrain; Phase 2. EPA-600/4-76-022. U.S. Environmental Protection Agency, Research Triangle Park, NC.

Ne74 Neter J. and Wasserman W., 1974, *Applied Linear Statistical Models.* Richard D. Irwin, Inc., Homewood, IL.

Nu77 U. S. Nuclear Regulatory Commission Regulatory Guide 1.111. 1977. Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors. U.S. Nuclear Regulatory Commission, Washington, D.C.

Sl68 Slade D. H. (Editor), 1968, *Meteorology and Atomic Energy.* TID-24190, U.S. Atomic Energy Commission, Washington, D.C.

Sn72 Snyder W. H., 1972, "Similarity Criteria for the Application of Fluid Models to the Study of Air Pollution Meteorology", *Bound.-Layer Meteorol.* **3**, 113–134.

Sn76 Synder W. H. and Lawson R. E., Jr., 1976, "Determination of a Necessary Height for a Stack Close to a Building—A Wind Tunnel Study," *Atmos. Envir.* **10**, 689–691.

Sn81 Snyder W. H., 1981, Guideline for Fluid Modeling of Atmospheric Diffusion. EPA-600/8-81-009. U.S. Environmental Protection Agency, Research Triangle Park, NC.

Th77 Thompson R. S. and Lombardi D. J., 1977, Dispersion of Roof-Top Emissions from Isolated Buildings—A Wind Tunnel Study. EPA-600/4-77-006, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Ya66 Yanskey G. G., Markee E. H. Jr. and Richter A. P., 1966, Climatography of the National Reactor Testing Station. IDO-12048, Idaho Operations Office, U.S. Atomic Energy Commission, Washington, D.C.

Su49 Sutton O. G., 1949, *Atmospheric Turbulence.* p. 111. Methuen.